

Upper Ocean Mixing

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LONG-TERM GOALS

To identify the major processes producing mixing in the upper ocean and to understand their dynamics sufficiently well to permit developing accurate parameterizations of mixing for use in numerical models.

OBJECTIVES

To understand mixing in exchange flows through straits and how it affects hydraulic control, and to relate mixing to shear on continental shelves.

APPROACH

To study mixing in an exchange flow likely to be affected by mixing, we worked with Emin Ozsoy of the Middle East Technical University to measure flow and mixing in the Bosphorus. To study mixing on a 'representative' continental shelf, we participated in the Coastal Mixing and Optics Experiment (CMO) on the New England shelf.

WORK COMPLETED

Jody Klymak completed his Ph.D. dissertation analyzing flow and mixing over the sill in Knight Inlet. He has completed two papers from the thesis and expects to submit a third shortly. Jennifer MacKinnon has completed her analysis of the CMO96 data and is preparing two papers about the results. Gregg and Ozsoy have completed the analysis of flow and hydraulics in their Bosphorus data and have several papers in press.

RESULTS

Contrary to previous assumptions about Knight Inlet, the flow was found to be fully three-dimensional except directly over the sill. Flow over the sills is part of a large-scale response to alternating tides that extends kilometers up and downstream and produces a steady oscillation of the density of water coming over the sill as well as the velocity. Strong horizontal eddies develop downstream of the sill and confine the mainflow in relatively narrow jets. Because Knight Inlet is relatively straight near the sill, these features should be expected in all sill flows, which previously had been assumed two-dimensional. Sills are found in nearly all straits, e.g. Gibraltar.

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Analysis of the Bosphorus observations revealed that the exchange flow was far from meeting the criteria for a two-layer hydraulic control. Such control had been widely assumed, but it is not surprising to find that it is not satisfied. The strait is shallow, narrow and long, providing many opportunities for friction to be large enough to violate the hydraulic assumptions.

The right panel of Figure 1 shows evidence for a large flow separation downstream of a point that occurs in a sharp bend in the narrowest part of the strait. The top of the density interface slopes steeply up toward the point. Southward flow is diverted strongly across channel and seems to follow the curved surfaces of the surfaces. Flow was negligible along the western (Asian) coast south of the point. Many other flow separations were found along the irregular channel.

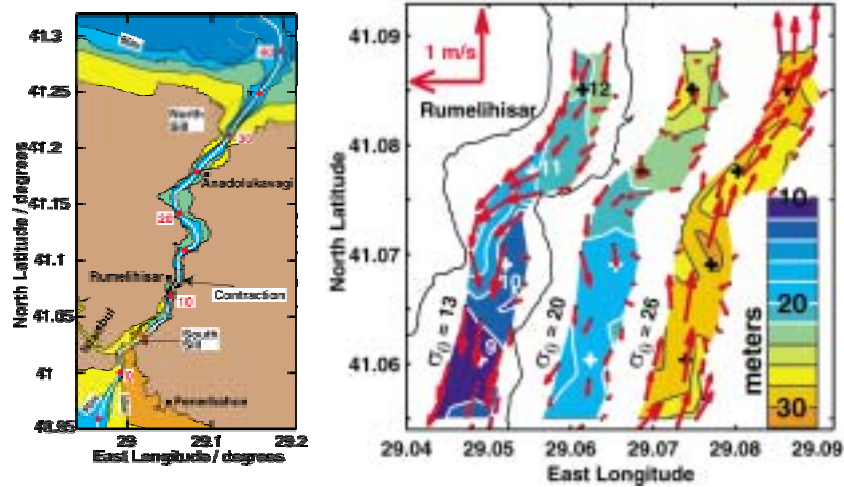


Fig. 1. The Bosphorus (left) joins the Black Sea (top) to the Sea of Marmara (bottom). Its narrowest section, the Contraction, is only 750 m from shore to shore. The expanded section through the Contraction (right) has maps of the depths of the top, middle, and bottom of the density interface, revealing the steep slope of the upper interface around the point opposite Rumelihisar. Intense mixing begins beneath the sloping surface, and the southward flow separates from the western shore downstream of the point. Crosses are marked at 1 kilometer intervals from the south end of the strait.

The upper part of the interface rises steeply upwards as a result of intense mixing that begins along the edges of the flow separation. Figure 2 contains images of acoustic backscatter along the center of the three lines taken to form the density surfaces shown in Figure 1. The brightly-colored parts of the images mark the presence of centimeter-scale temperature and salinity fluctuations strong enough to scatter acoustic energy back to the ship. The patterns are similar to those found in radar backscatter from shear instabilities in the atmosphere and are confirmed by density inversions and elevated dissipation in the microstructure records. These instabilities and the flow separations are likely sources of frictional, rather than hydraulic, control of the exchange flow.

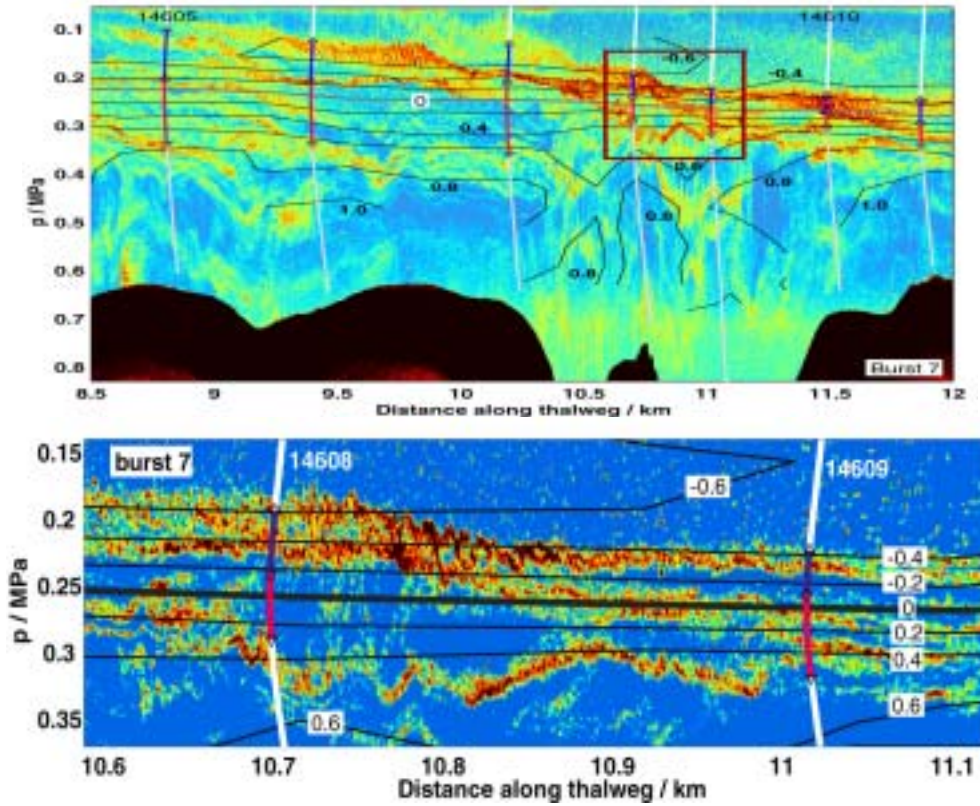


Fig. 2. Images of 200 kHz acoustic backscatter along the center of the channel through the Contraction in the Bosphorus, over the same section shown in Fig. 1. The images are colored by the intensity of the backscatter, with red and then black as the most intense and blue as the least. Velocity isotachs are overlaid as black lines. Positive velocities are northward. Vertical lines are trajectories of our microstructure profiler and are colored blue while in the upper half of the density interface and red in the lower half. The lower image is an expanded view of the box in the left image and resolves some of the ‘cat’s eye’ structures characteristic of overturning billows. (Gregg and Ozsoy, 2001)

Before mixing over continental shelves can be parameterized, the internal wave field producing the background mixing must be understood and described quantitatively. Murray Levine’s revision of the Garrett-Munk internal wave model provides a framework for internal waves in shallow water. Examining the same CMO data, however we find that the model does not work nearly as well for shear as it does for velocity. Figure 3 demonstrates that the first internal mode contains more than half of the kinetic energy, unlike the situation in the open ocean. The shear variance is spread over the first five modes, whose amplitudes rise and fall every few days in response to passing wave groups.

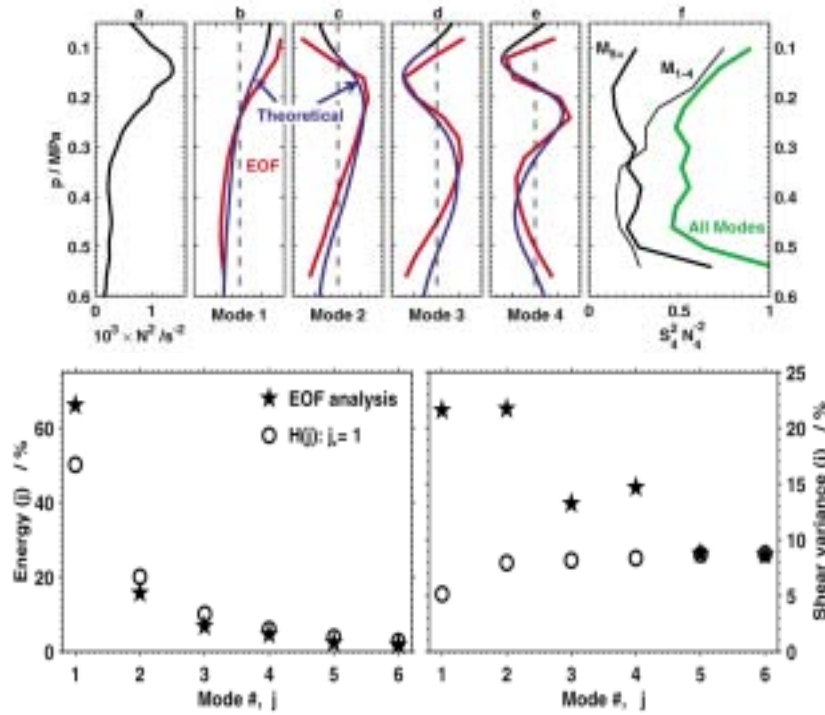


Fig. 3 *Decomposition of baroclinic velocity on the New England shelf into normal modes. The upper panel compares modes calculated using linear internal wave theory and the observed density profile (Theoretical) with empirical orthogonal functions (EOFs) of the observed velocity profiles. The lower panel compares contributions of the modes to the total kinetic energy (left) and shear variance (right) to the distributions given by the Garrett and Munk internal wave mode function, $H(j)$. The latter is a good representation for kinetic energy but not for shear. (MacKinnon and Gregg, 2001).*

IMPACT/APPLICATIONS

The results from Knight Inlet and the Bosphorus extend understanding of flows through straits by finding the limits of the very idealized hydraulic assumptions. This understanding is needed to understand flows through straits and then to learn how to apply that understanding to developing accurate local models and to entering the effects of straits in large-scale models.

Presently, there is little basis for choosing the mixing rates used in numerical models of flows over continental shelves. This work is the start of an attempt to put realistic mixing rates into littoral models.

TRANSITIONS

none

RELATED PROJECTS

Hawaii Ocean Mixing Experiment (HOME) and Arlindo.

PUBLICATIONS

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